Content

- Introduction & Opportunity for ITO Alternative
  - CLEVIOS™ PEDOT:PSS
  - Flexibility vs. ITO
  - Applications

- Results of Roll to Roll Coating
  - Range of Surface Resistivities
  - Color
  - Coating Uniformity

- Dry Transfer of PEDOT:PSS

- Hybrid Structures

- Patterned PEDOT:PSS layers

- Summary
The Heraeus Group

**Conductive Polymers Division** Acquired by Heraeus-December 1, 2010

We are a global **precious metals and technology Group** with firm roots in Germany. The company has been **family-owned** for 160 years.

Precious metals, sensors, electronic materials, biomaterials and medical products, dental products, quartz glass, and specialty light sources are the focus of our activities.

Approximately 12,900 employees in over 120 subsidiaries.
Opportunity

- Address emerging opportunities for transparent conductive films with enhanced flexibility and durability
- ITO is well positioned for certain applications
- New devices will need improved performance
  - Improved physical properties
  - Improved cost control
PEDOT vs. ITO – physical robustness*

Dramatic improvement in conductivity under strain

20,000 X improvement!

Neovac ITO/PET – 4 Pl Clamps
Rs = 280 Ohm/Sq actual

Normalized Resistance Change (dR/R)
Stress

PEDOT vs. ITO
– physical robustness*

Data Courtesy of Eastman Kodak

* Dr. Ron Lubianez
AIMCAL Web Coating Conference 2011, October 23-26 Reno, NV

ITO/PET

PEDOT/PET
Applications

- **Resistive Touchscreens**

- **Conductive electrodes for Polymer dispersed LC (PDLC) displays**

- **Semi-conductive coatings on electrodes for PDLC displays**
CLEVIOS™ PEDOT:PSS

- Water-based dispersion of the polymer complex poly(3,4-ethylenedioxythiophene)/polystyrene sulfonate (PEDT/PSS or PEDOT/PSS)
- Submicrometer sized gel particles
- Produced at the Heraeus site in Leverkusen, Germany.
- Forms a continuous film upon drying

Chemical structure

Schematic picture of a dispersed gel particle
KODAK HCF Film ESTAR Base*

- **PEDOT**
- **Primer**
- **2.5 to 7 Mil Clear PET**
- **Primer**
- **Optional functional layer**

<table>
<thead>
<tr>
<th>SR</th>
<th>VLT</th>
<th>Haze</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>86.2</td>
<td>0.89</td>
</tr>
<tr>
<td>230</td>
<td>88.3</td>
<td>0.83</td>
</tr>
<tr>
<td>350</td>
<td>91.7</td>
<td>0.92</td>
</tr>
<tr>
<td>250 (ITO)</td>
<td>87</td>
<td>1.02</td>
</tr>
</tbody>
</table>

*Data Courtesy of Eastman Kodak Company*
Cross-web Surface Resistivity Uniformity of PEDOT:PSS*

Dr. Ron Lubianez - AIMCAL Web Coating Conference 2011, October 23-26 Reno, NV

* Data Courtesy of Eastman Kodak Company
Dry-transfer of PEDOT*

- Same SR before and after transfer
- Transfer without residue (ascertained by XPS)
- Surface roughness ~ 5nm (measured by AFM)

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*Courtesy of Eastman Kodak Company
Laser Transfer of PEDOT*

SR ~ 600 ohms/square

Donor: PEDOT/TAC

Receiver: PVDC primed PET

10 Hz  3.5 in scan
23 x 85 μm beam
3.4 J/cm²

*Courtesy of Eastman Kodak Company
Dry-transfer of PEDOT and Silver*

<table>
<thead>
<tr>
<th>SR (PEDOT/Ag)</th>
<th>Transmission</th>
</tr>
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<tbody>
<tr>
<td>3 ohms/square</td>
<td>42%</td>
</tr>
<tr>
<td>7 ohms/square</td>
<td>58%</td>
</tr>
<tr>
<td>22 ohms/square</td>
<td>64%</td>
</tr>
</tbody>
</table>

*Courtesy of Eastman Kodak Company

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Challenges and Solutions

- **Environmental stability***

<table>
<thead>
<tr>
<th>HCF 230</th>
<th>150C / 1h</th>
<th>85C / 85%RH 500h</th>
<th>60C / 90%RH 240h</th>
</tr>
</thead>
<tbody>
<tr>
<td>232.5 ohm/sq</td>
<td>+1.4%</td>
<td>+6.8%</td>
<td>-2.7%</td>
</tr>
</tbody>
</table>

- **Electrical performance**
  - **Hybrid structure**
**PEDOT:PSS Formulation for Conductive Electrodes**

- A ready to use Clevios Formulation for Conductive Electrodes
- Smooth film formation over bus bars

### Material properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
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<tbody>
<tr>
<td>Solids content</td>
<td>2.9%</td>
</tr>
<tr>
<td>Conductivity</td>
<td>120 S/cm</td>
</tr>
<tr>
<td>Viscosity</td>
<td>30 mPas [20°C]</td>
</tr>
<tr>
<td>Typical layer thickness</td>
<td>200 – 800 nm</td>
</tr>
<tr>
<td>Sheet resistance for 700 nm thick layer</td>
<td>85 Ohm/sq</td>
</tr>
<tr>
<td>Internal transmission for 700 nm thick layer</td>
<td>72%</td>
</tr>
</tbody>
</table>

Typical values - not specifications
CLEVIOS™ F CE

- 12.5 cm² OLED on PET
- Low leakage current (I < 0.1 mA @ 1 V)
- Efficient device η = 1.0 cd/A

Ag busbar

PET

Clevios F CE (700 nm)

Clevios P Al 4083 (50 nm)

α - NPB

Alq

Li/F

Al

Ag-lines printed by OPTOMEC™

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Invisible Wet ETCH Process

- Wet etching process specifically for CLEVIOS™ PEDOT:PSS films

coat CLEVIOS™

development

coop photoresist

UV expose

etch with CLEVIOS™ Etch

resist removal

non-conductive

conductive
## CLEVIOS™ ETCH

<table>
<thead>
<tr>
<th>Properties</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Suitable solvent</td>
<td>water</td>
</tr>
<tr>
<td>Etching time</td>
<td>60 s (10% solution)</td>
</tr>
<tr>
<td>Surface resistance before etching</td>
<td>200 – 400 Ohm/sq</td>
</tr>
<tr>
<td>Surface resistance after etching</td>
<td>&gt; $10^9$ Ohm/sq</td>
</tr>
</tbody>
</table>

**Easy** Preparation:
1) Dissolving 1 part Etchant in 9 parts of water
2) Stirring for 30 min
3) Filtration by 5 µm Polypropylene-Filter
A High Conductive PEDOT:PSS coated curved PET-substrate has been structured into strips using Clevios™ ETCH.

The non-conductive and conductive areas have the same transparent appearance. The adjacent conductive segments are electrically bridged with LEDs. The result is clear illumination, with no apparent electrical connections.

\[
U_{DC} = 36V
I = 3mA
\]

Advantages:
- Invisible structure
- Flexible
- Long term stability
Summary

- Cost Effective Opportunities Exist for Robust Flexible Alternative to ITO for Transparent Electrode Applications
- Multi-Roll to Roll Coating of PEDOT:PSS Demonstrated with Excellent Coating Uniformity and Environmental Stability
- Dry Transfer and Hybrid Structures of PEDOT:PSS for ITO-Free Devices
- Novel Invisible Wet-Etch Process for Patterning Transparent High Conductive Coatings of PEDOT:PSS
Acknowledgements

- Dr. Andreas Elschner, Mr. Udo Guntermann & Dr. Wilfried Lövenich - Heraeus Precious Metals GmbH & Co. KG-Conductive Polymers Division (Clevios)-Leverkusen, Germany

- HCF Team at Eastman Kodak in Rochester, NY

Building B 202 ChemPark Leverkusen